Analyzing Power Plant Strategies for Carbon Capture

Edward S. Rubin
Department of Engineering and Public Policy
Carnegie Mellon University
Pittsburgh, Pennsylvania

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Objectives

• Compare the performance and cost of current fossil fuel power systems with and without CO₂ capture and storage (CCS)
  • Pulverized coal combustion (PC)
  • Integrated coal gasification combined cycle (IGCC)
  • Natural gas combined cycle (NGCC)
• Characterize and quantify the major resource requirements and multi-media environmental emissions associated with these systems
Recent CO₂ Capture Cost Estimates
(includes compression, but excludes transport & storage costs)

Cost of Electricity ($/MWh)

Reference Plant with Capture

Natural gas cost = $2-3/GJ; coal cost approx. $1-2/GJ. IGCC data for bituminous coals only. Other assumptions vary.
What’s New Here?

• For cost comparisons, we explore a broader range of assumptions/conditions that influence the cost of these technologies (with and without capture)
• We include CO₂ transport and storage costs
• We highlight the implications of CCS energy requirements on plant-level resource consumption and ancillary environmental impacts
• We use the (publicly available) IECM computer model (Version 4.0.4) to evaluate all three systems

Results for Baseline Case Study Assumptions

(500 MW, 75% CF, Pgh#8 Coal, $4/GJ Gas)
CO₂ Emission Rates (kg/MWh)

Cost of Electricity (COE)
(Levelized $/MWh)
Effects of Fuel Price and Plant Dispatch

Recent Trends for Natural Gas Price and NGCC Plant Utilization
Cost of Electricity, Revisited
(Levelized $/MWh)

Differences in Total Variable Operating Cost w/ CCS ($/MWh)
(Includes fuel, chemicals, utilities, wastes and byproducts)

<table>
<thead>
<tr>
<th>Plant</th>
<th>Fuel Price</th>
<th>CCS Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>$1.2/ GJ</td>
<td>(Base case)</td>
</tr>
<tr>
<td>IGCC</td>
<td>$1.2/ GJ</td>
<td>– 9</td>
</tr>
<tr>
<td>NGCC</td>
<td>$2.2/ GJ</td>
<td>– 7</td>
</tr>
<tr>
<td></td>
<td>$4.0/ GJ</td>
<td>+ 8</td>
</tr>
<tr>
<td></td>
<td>$5.8/ GJ</td>
<td>+24</td>
</tr>
</tbody>
</table>

Implication: Increasing dispatch of IGCC, and less use of NGCC, when CCS is added
Cost of Electricity ($/MWh) w/ Differential Capacity Factors

- Gas @ $4.0/GJ
- + capture
- + transport & storage

<table>
<thead>
<tr>
<th>Type</th>
<th>PC</th>
<th>IGCC</th>
<th>NGCC</th>
<th>PC</th>
<th>IGCC</th>
<th>NGCC</th>
<th>PC</th>
<th>IGCC</th>
<th>NGCC</th>
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</thead>
<tbody>
<tr>
<td>CF=75%</td>
<td>62</td>
<td>64</td>
<td>62</td>
<td>74</td>
<td>68</td>
<td>68</td>
<td>68</td>
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<tr>
<td>CF=85%</td>
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<td>70</td>
<td>74</td>
<td>74</td>
<td>74</td>
<td>68</td>
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<tr>
<td>CF=50%</td>
<td>82</td>
<td>82</td>
<td>82</td>
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</tr>
</tbody>
</table>

Baseline Case: CF = 75% (all plants)

Effects of IGCC
Financing & Operation
IGCC — Can You Build It?
Two New Scenarios

- **“Unfavorable” Case**
  - Risk premium on financing (FCF=17.3%)
  - Lower plant utilization (CF=65%)

- **“Favorable” Case**
  - Risk sharing by 3rd parties (FCF=10.4%)
  - Higher plant utilization (CF=85%)

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Cost of Electricity ($/MWh) for Two New IGCC Scenarios

![Cost of Electricity Chart]

- Steps = Baseline + FCF + CF

**Unfavorable**
- Ref. Plant: 48, 54, 61, 70, 78, 86
- CCS Plant: 48, 39, 35, 70, 57, 52

**Favorable**
- Ref. Plant: 48, 39, 35, 70, 57, 52
- CCS Plant: 48, 39, 35, 70, 57, 52

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CCS Energy Penalty Impacts on Resource Consumption and Multi-media Emissions

• We define the CCS energy requirement as the increase in energy input per unit of product output.

• This measure directly affects the plant resource requirements and environmental emissions per kWh generated:
  - Plant fuel consumption
  - Other resource requirements
  - Solid and liquid wastes
  - Air pollutants not captured by CCS
  - Upstream (life cycle) impacts

• For case study plants, energy input increases by:
  - PC = 31%;  IGCC = 16%;  NGCC = 18%
Case Study Increases in Fuel and Reagent Consumption

Increases in Coal and Natural Gas Consumption

- PC
- IGCC
- NGCC

Increases in Ammonia Consumption

- PC
- IGCC
- NGCC

Increase in Limestone Consumption

- PC
- IGCC
- NGCC

Case Study Increases in Solid Wastes & Plant Byproducts

Increases in Ash or Slag Residues

- PC
- IGCC

Increases in Desulfurization System Residues

- PC
- IGCC
- NGCC
Case Study Increases in Air Emission Rates

Conclusions from Case Studies

- Many of the key factors and inter-dependencies affecting CO₂ capture costs for fossil fuel power systems have not been considered in past studies; their inclusion can significantly alter the outlook for competing options.

- Current CO₂ capture systems can significantly exacerbate the multi-media environmental impacts and resources required to produce useful products like electricity.

- Minimizing CCS energy requirements is essential for minimizing these adverse impacts.
The Critical Importance of Technology Innovation

- New or improved technologies for power generation and CO$_2$ capture can lower the cost of CCS, and significantly reduce adverse secondary impacts by:
  - Improving overall plant efficiency
  - Reducing CCS energy requirements
  - Maximizing co-capture of other pollutants

Work in Progress at CMU

- **Incorporate performance and cost models of advanced power systems and CO$_2$ capture options:**
  - Oxyfuel combustion
  - ITM oxygen production
  - Advanced IGCC designs
  - Advanced NGCC

- **Expand and regionalize transport & storage models**

- **Comparative analyses of CO$_2$ capture options for new and existing power plants**
  - Advanced PC, NGCC and IGCC systems
  - Repowering or rebuild of existing units

- **Assessments of R&D Benefits**
The IECM is Available At . . .

• Free Web Download:
  • www.iecm-online.com

• Technical Support:
  • PED.modeling@netl.doe.gov

• Other Inquiries:
  • mikeb@cmu.edu
  • rubin@cmu.edu